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Relict grains in CAIs, revisited. D. S. Burnett, M. L. Johnson[1] and D. S. Woolum.[2] [1]Caltech, Pasadena, CA 91125, USA. [2]Calif. State Univ., Fullerton, CA 92634, USA.

Although the Type B CAI are clearly igneous rocks, they were probably not completely molten (1, 2), thus the possibility exists that preexisting materials can be recognized and characterized. Relict phases were proposed to explain high U and Th concentrations in both melilite and fassaite which would require unreasonably high partition coefficients (D) if due to crystal-liquid partitioning (3). More detailed study showed very rare perovskite grains and enigmatic Ti hot spots in melilite (4). Kuehner *et al.* (5) subsequently reported very high lithophile trace element contents, including actinides, for fassaite inclusions in melilite which they proposed as relict phases, but Simon *et al.* (6) show that the fassaite inclusions can be better explained as being the last drops of liquid crystallization. In any case, the original observations and interpretations of (3) still point to an actinide-rich relict host phase.

To be able to say what levels of Ti, U, and Th in melilite can be explained by igneous partitioning, we have measured D(mel) for these elements in a synthetic CAI composition under controlled fO_2 conditions, extended down to nebular conditions by carrying out experiments in graphite crucibles in pure CO. Actinide partition coefficients are quite low: D(Th) = 0.008 and D(U) = 0.0007 (possibly a record low in measured D values). The D for trivalent U should be around 0.1–0.3 depending on Ak content as the ionic radius of U^{+3} is similar to La. Thus, for solar nebula fO_2's and CAI compositions less than 1% of the U is trivalent. The measured D prove that igneous partitioning fails to explain the average U contents of type B CAI melilites, the difference being a factor of 600. D(Ti) is 0.018 at Ak23 and increases with Ak content. D(Ti) is relatively similar in air and at solar nebula fO_2s, surprising given the documented importance of trivalent Ti. In any case, the measured D(Ti) show that melilite Ti levels around 200–300 ppm in early crystallizing melilite can be explained by igneous partitioning, but higher levels would be indicative of resorbed Ti-rich relict phases (*e.g.,* perovskite).

To make a closer comparison of U and Ti in CAI melilites, the fission track images of (3) have been quantitatively mapped at 20 microns resolution for two mm-sized rim and one mantle melilite. High resolution quantitative U distribution data on adjacent fassaites were also obtained. One rim grain shows several U-rich fassaites like those of (5), but the other melilites do not. There are broad U-rich regions in all grains which will be characterized in more detail. The mantle grain is especially rich in detail, but some of this may be correlated with secondary alteration. There is rough correlation of U content and Ti in the rim grains, but the scale of the Ti analyses, based on electron probe points, is much smaller than that for U. If relict phases, *e.g.,* perovskite, dominate the actinide distributions, they might also affect other lithophile trace elements, *e.g.,* REE. References: (1) Wark D. (1983) thesis. (2) Stolper E. and Paque J. (1986) *Geochim., Cosmochim.* **50,** 2159. (3) Murrell M. and Burnett D. (1987) *Geochim. Cosmochim.* **51,** 985. (4) Johnson M., Burnett D. and Woolum D. (1988) *Meteoritics* **23,** 276. (5) Kuehner S., Davis A. and Grossman L. (1989) *Geophys. Res. Lett.* **16,** 775. (6) Simon S., Davis A. and Grossman L. (1990) *LPSC* **21,** 1161.

Origin of Ithaca Chasma on Tethys (S III) as a result of the Odysseus cratering event. E. S. Bus* and H. J. Melosh. Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA. *(new name: E. S. Howell).

Tethys is dominated by two major topographic features, the crater Odysseus, the largest in the Saturn system, and Ithaca Chasma, a huge complex graben system. On the leading hemisphere of Tethys, Odysseus is 400 km in diameter, nearly 80% of the satellite radius. Only the rims remain from this fully relaxed crater, the floor having rebounded above the rim to match the convex curvature of the satellite. Ithaca Chasma extends over 2000 km, is 3–4 km deep, and typically 100 km wide, encompassing an area nearly 10% of the satellite's surface This terraced chasm follows a great circle approximately 90° from Odysseus, extending nearly ¾ of the way around the satellite. Based on this evidence, Smith *et al.* (1982) and others have suggested that Ithaca Chasma may have formed as a result of relaxation after the Odysseus impact event.

In order to test the hypothesis that Ithaca Chasma could result from the relaxation of the crater Odysseus, we use the finite element method to model Tethys. As demonstrated by Hillgren and Melosh (1989), the visco-elastic properties of ice dominate the tectonics of icy satellites and both short and long timescale responses of the material must be included in a realistic model. In our time dependent model, the elastic response of the satellite is determined at each timestep, and the displacements are used to calculate the stress and strain rate in each element. The interplay of the short timescale elastic behavior and the long timescale viscous behavior of a material such as ice is complex. However, with the appropriate choice of timesteps, finite element models can give accurate results for the physical response of a system to applied stress such as a crater relaxing under gravity.

Thomas and Squyres (1988) have also used a finite element method to calculate the fluid flow in a purely viscous body when the crater is a significant fraction of the body radius. They find for larger craters, extensional stresses can develop 90° from the crater, supporting the idea that a graben could result. However, their model does not include a rigid lithosphere, which could substantially alter the flow.

We model a lithosphere of variable thickness, with different material properties possible for each layer within the satellite. The crater is introduced, and the stress field as a function of time and position is calculated for the entire body. We will explore the parameter space of lithosphere thickness and material properties that would lead to the formation of Ithaca Chasma. This model allows for the introduction of faults, and thus we can determine the expected displacement given tensional stresses 90° from the crater, and compare it with the observed dimensions of the chasm. The results of these models and constraints on the interior structure of Tethys imposed by the existence of Ithaca Chasma will be presented. References: Hillgren V. J. and Melosh H. J. (1989) *GRL* **16,** 1339. Smith B. A. *et al.* (1982) *Science* **215,** 504. Thomas P. J. and Squyres S. W. (1988) *JGR* **93,** 14919.

Rubble-pile parent bodies, asteroids, and satellites. C. R. Chapman. Planetary Sci. Inst., 2421 E. 6th St., Tucson AZ 85719, USA.

Many of the smaller objects in the solar system may have the general characteristics of a "rubble pile." The term was first introduced (1) in the context of models for asteroid collisions to describe the presumed outcome of collisions that are more than sufficiently energetic to shatter an asteroid, but insufficiently energetic to disperse the fragments, which fall back together into a non-cohesive aggregate. Since then, the concept has been widely adopted and better quantified in studies of asteroid fragmentation (2), and it has been applied with increasing frequency to model meteorite parent bodies in order to interpret meteoritical data (3, 4).

This work reviews recent research on asteroidal rubble piles, and considers several important implications for asteroid populations, meteorite parent bodies, and reaccumulated planetary satellites. Rubble piles are formed preferentially for moderately large asteroids, of order 100 km diameter. It is unresolved how collisions might produce numerous small rubble piles, but several problems—including radar observations of the binary configuration of the small asteroid 1989 PB (5) and possibly other Earth-approachers—could be resolved if break-up of large asteroids yields rubble piles of small dimensions. Rubble-pile structure for Earth-approaching asteroids may have consequences for Earth-impact scenarios.

Lightcurve data, even for asteroids very likely to be rubble piles, are generally not compatible with the idea that they exhibit quasi-equilibrium shapes (6). Shapes of single-generation rubble piles may be irregular, dominated by the largest constituent pieces. Multiple-generation rubble piles may be less irregular, with departures from equilibrium shapes more affected by the largest cratering impacts.

Asteroid size distributions and family characteristics may be strongly affected by the process of creating rubble-piles, in particular enhancing the numbers of 100 km objects relative to objects half that size.

Reaccumulation of planetary satellites enhances production of multigeneration, comminuted rubble piles, provided there are large enough impact frequencies. The apparent absence of small Neptunian satellites (7) may be due to the "rubble-pile energy gap."

Regardless of the dimensions of a meteorite's immediate parent body,